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PROCESSING OF ALUMINIUM METAL MATRIX COMPOSITES - A REVIEW

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ABSTRACT

Aluminum matrix composites are the competent material in the industrial world. They are widely used in aerospace, automobile, marine industries, etc. due to their excellent mechanical properties. Development of these lightweight materials has provided the automotive industry with numerous possibilities for vehicle weight reduction. The various routes are used to synthesize AMCs. Among the various manufacturing processes, the conventional stir casting is an attractive processing method for producing AMCs as it is relatively inexpensive and offers a wide range of materials and processing conditions. In this review paper we have discussed about aluminum matrix composites and its synthesizing techniques with the help of previous research reports. The current research activities going in this field is also discussed in this paper.

Keywords: *AA 6063, TiC, stir casting process.*

1.Introduction

Aluminum metal matrix composites have been attracting growing interest in these days [1]. Composite materials are two or more constituents are combined on microscopic scales to synthesize a useful material. The advantage of the composite materials is that their individual constituents retain their characteristic unlike alloys. Composite consist two phases such as matrix and reinforcement. Matrix phase having a continuous character, usually more ductile and less hard phase and holds the reinforcing phase and shares a load with it. Reinforcing phase is embedded in the matrix in a discontinuous form, usually stronger than the matrix. The reinforcements may be either harder or softer than the matrix alloy and affect the properties of the composites. The nature of the reinforcing phases and the matrix are the important factors on the basis of which composite materials are classified in Fig.1. For engineering purposes, metal, ceramic, glass, and organically derived synthetic fibers are more significant. The rule of mixtures is a method of approach to approximate estimation of composite material properties, based on an assumption that a composite property is the volume weighed average of the phase properties. The MMCs are composed of a metal matrix namely Al, Mg, Fe, Cu, etc. and a dispersed ceramic reinforcement such as silicon carbide, titanium carbide, boron, alumina, silicon nitride, boron carbide, boron nitride etc. [2].

Metal matrix composites are used for space shuttle, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs and a variety of other applications. Aluminum alloys have been the material of choice for aircraft construction since the 1930s. The 6xxx can be used in a variety of applications including aircraft fuselage skins and automobile body panels and bumpers, instead of more expensive 2XXX and 7XXX alloys, after appropriate heat treatments [3]. The main components of heat treatable 6xxx series aluminum alloy are Mg and Si, and 6xxx derives its strength from the precipitation hardening phase, Mg_2Si [4].

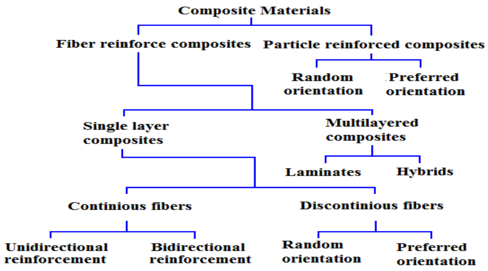

Fig. 1 Classification of composites

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The volume fraction of Mg_2Si is affected primarily through the level of Mg within the alloy, but the Si content is also important. The increasing Si in 6XXX type alloys increases strength in the T4 and T6 tempers. Al-TiC composite is a new class of metal matrix composite materials with distinct properties over the alloy materials. This literature review of open source emphasizes that there are only few reports exists in the area of microstructure, forming and machinability of composite materials particularly Al-TiC composites.

2. Methods for Fabricating AMCs

There are two basic techniques in making of metal matrix composite such as solid phase techniques and liquid phase techniques. The solid phase techniques such as powder metallurgy, diffusion bonding and plasma transferred. The liquid phase techniques are, squeeze casting, vacuum infiltration techniques, stir casting and compo casting**.** Saravanakumar et al. has reviewed various manufacturing techniques to achieve uniform distribution of TiC reinforcements in Al matrix [5]. Al-TiC particulate metal matrix composites were produced by in-situ synthesis process, powder metallurgy, friction stir process, stir casting respectively. In-situ techniques involve a chemical reaction resulting in the formation of a very fine and thermodynamically stable reinforcing ceramic phase within a metal matrix. It provides thermodynamic compatibility at the matrix-reinforcement interface. In solid synthesis processes, high purity titanium and carbon powder and aluminium powder were mixed together, compact this mixture and heated from top to begin the formation of reinforcements.

In powder metallurgy technique, the matrix and reinforcement powders are blended and pressed hydraulic press and then it is sintered in controlled atmosphere and extruded for consolidation. Powder metallurgy is a popular method for fabrication of composite to close dimensional tolerances, with minimum scrap and fewer secondary machining operations. Alpas et al. produced Al-TiC composite through powder metallurgy route with optimal TiC and Al powder were mixed for a longer duration to achieve uniform distribution of TiC particle [7]. The mixed powder was compacted at a pressure of 300-500 MPa with zinc as a lubricant. This compacted product was sintered at 500-550^{o}C with a socking time of 2-3 hours under argon atmosphere and then subjected to furnace cooling. The powder metallurgy may not be an ideal processing technique for mass production.

Diffusion bonding process is used to produce metal matrix composite as boron filaments in to a titanium matrix. It assures quality of bond strength and ductility of parent metal. ElZhang et al. successfully fabricated Al-TiC composite by using diffusion processes [6]. When concentration of Ti powder around aluminium reaches 0.15 wt. % precipitate reaction happens and Al_3Ti phase is formed around the Ti powder.

In the plasma transferred arc system, the blended matrix and reinforcement powders were fed in to plasma arc column generated between a ‘w’ shaped electrode and water cooled copper mold substrate. Argon gas is generally used for plasma generation and for feeding metal and ceramic powders.

In liquid state synthesis process, TiC particles are formed by addition of gaseous phase and precipitates phase into a liquid metal/alloy. The reaction kinetics for formation of TiC particles in-situ in the Al melt depends on various factors like temperature, reaction time, Ti: C ratio. Also the interfacial reaction product will cause disturbance in mechanical and thermal properties of composites.

In squeeze casting process molten metal is poured in to a preheated tool steel die with powder preform assembly of the reinforcement material. In vacuum infiltration techniques preform of reinforcement is prepared and the molten metal is made to infiltrate in to preform by applying vacuum pressure.

In stir casting process, a dispersed phase is mixed with a molten matrix metal by means of mechanical stirring. The specially designed impeller and the reinforcement particles are introduced in vortex created. The composite is high stiffness, high strength and compatibility to produce low cost compared to other production process. In stir casting process, powder reinforcements are distributed into molten metal by means of mechanical stirring process. Production of MMC’s using this process can be effect by process variables such as holding temperature, stirring speed, size of the impeller, and the position of the impeller in the melt which has impact on mechanical properties. Stir casting technique (is shown in Fig. 2) is best and easy process for production of Al-TiC PMMC than any other methods. The properties of metal matrix composites are strongly depending upon the interfacial bonding strength of reinforcement and matrix phase [9].

Frictions stir processing is also one of the methods to fabricate TiC reinforced aluminum matrix composite [8]. The tool movement is in the same direction of the tool rotation, whilst it is retreating if the tool moves in the opposite direction. It has been basically advanced as a grain refinement technique; it is a very attractive process for fabricating composites.

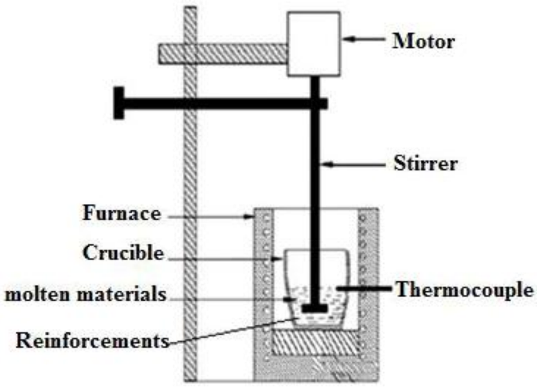

Fig. 2 Stir casting process set up

In compo casting technique the metal is stirred isothermally within the freezing range during mixing and again brought to molten condition for second stage string and casting.

Waldemar et al. [10] has worked the mechanical and micro structural characterization by optical and electron microscopy as well as micro hardness of Al 6063 alloy after mechanical and thermal treatment. The Al-Mg based alloys have special attention due to the lightness of the material and certain mechanical properties and recyclability. It produces good mechanical properties in moderate mechanical efforts (up to 700 MPa) and good resistance to the corrosion [51].

Gao et al. [11] has dense and defect-free NiAl/TiC composites with TiC content as high as 86-92 vol. % were successfully produced by an indirect upward and pressure less melt infiltration at 1750°C. The high content of TiC and consequent TiC particles joining were obtained by pre-sintering of the as-pressed TiC preform before infiltration. The four-point bending strength and indentation toughness are higher than predicted using the normal rule of mixture, which is attributed to the interpenetrating microstructure. The combination of the de-bonding of TiC and NiAl interface and the cleavage of TiC grains are the main fracture mode of the composites, but the thin NiAl in the composites still acted as crack bridging during fracture.

Figure 3 (a & b) presents the optical micrographs of aluminium composites reinforced with 10% of SiC. Specimen sintered at 700°C, 750°C and 800°C, the particles were distributed uniformly and dendrite structure was more obvious in the microstructure. There is no large pore and particles clustering existed in these micrographs.

However, the other two composites (at 850°C and 900°C) having pores and particles clustering. The existence of pores and particle clustering was attributed to the high viscosity and low shearing rate of the melt. The tension test revealed that ultimate strength increased gradually up to 800°C and starts to decrease gradually due to the distribution in the Al matrix with increase holding time. It is revealed that holding time influences the viscosity of liquid metal, particles distribution and also induces some chemical reaction between matrix and reinforcement. The hardness values increases more or less linearly with increasing of processing temperatures from 750°C to 800°C at 20 minutes of holding time.

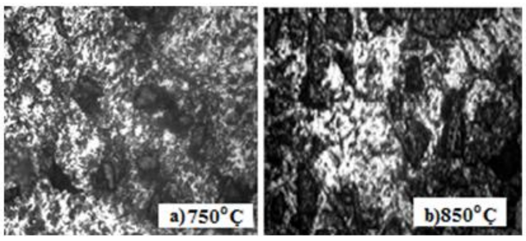

Fig. 3 Optical image shows particles distribution at 20 minutes holding time [12]

Farouk Shehata et al. [13] had produced conventional metal matrix composites with fairly homogenous dispersion of reinforcement material. Commercial pure aluminum and silicon carbide particles were selected as matrix and reinforcement materials. The matrix was first completely melted and kept constant at 750°C. Then SiC powder preheated to 800°C was added during stirring action. The melt mixture was poured into a metallic mold.

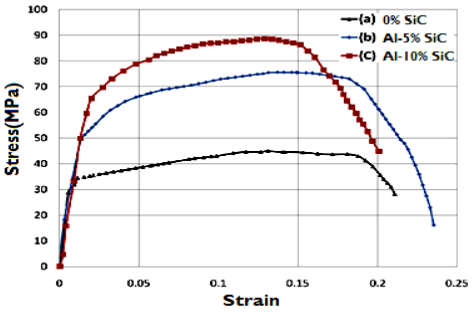

Fig. 4 Engineering stress-strain curves from tension tests of as cast composites [13]

Figure 4 shows the tensile engineering stress-strain curves for as cast composites Al-5% SiC and Al-10% SiC and it is compared with pure aluminum matrix material. These curves are drawn from the load-elongation obtained from the tensile testing machine. Figure 5 shows the compression engineering stress-strain curves for as cast composites; Al-5% SiC and Al-10% SiC compared to pure aluminum matrix. Again these curves are taken from the engineering load reduction in height curves obtained from the compression testing machine. These curves showed that, increasing the content of SiC reinforcement particles increased the compressive strength of the composite. In compression tests, at 20% reduction in height, the compression strength showed a significant increase with increase of silicon carbide content in the matrix up to 5% SiC. Further increase in SiC to 10% also showed an increase in compression but with lower rate. The increase in compression strength is much higher than that the corresponding increases in tension strength.

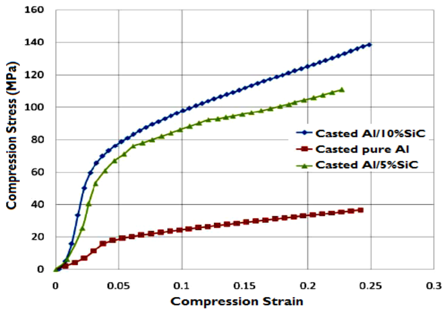

Fig. 5 Engineering stress-strain curves from compression tests of as cast composites [13]

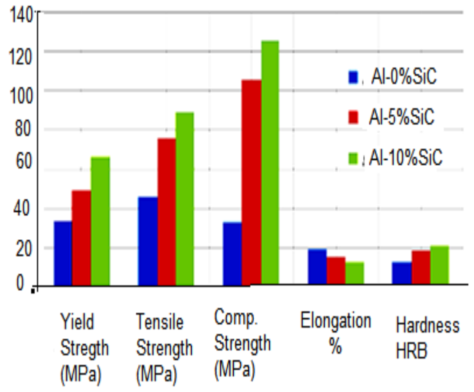

Fig. 6 Comparison of mechanical properties with different percentages of SiC [13]

Figure 6 shows a comparison of various mechanical properties of pure aluminum, Al-5% SiC and Al-10% SiC composites synthesized by stir casting before conducting ECAP process. The yield and ultimate tensile strengths in both composites increased with increasing SiC wt. % compared to pure Al. The maximum strength was found for Al-10% SiC MMC. The ultimate tensile strengths of both composites showed an increase of 97% and 68% over the corresponding value of the as cast pure Al. The compression strength showed more increase of 297% and 218% over the corresponding value of as cast pure Al. The improvement in strengths of MMC is resulting from the effective dispersion of the SiC particles fabricated by stir casting method. It can be attributed to closure action of any micro cracks that might appear. It should be noticed that there were no fracture in compression specimens due to the high ductility nature of the pure aluminum matrix. Hardness increased to 1.5 times its value in the as cast composites after one ECAP pass. The maximum hardness of 71 HRB obtained after 8 passes, which is almost 3.5 times the corresponding values of the as cast MMC composites.

The influence of thermo-mechanical treatment on the porosity and mechanical performance of SiC reinforced AA6063 composites [14]. AA6063-SiC composites with 6 and 9 volume % of SiC were fabricated by double stir casting process. The composites were cold rolled to 20, 25 and 35% deformation before solution heat treating at 550°C for 1 hour cooling rapidly in water. The results of the density measurements and percent porosity of the as-cast, 20, 25 and 35% cold rolled and solution heat treated AA6063/SiC composites were observed for all volume percent. The as-cast tempered had the highest porosity levels in comparison with the cold rolled and solution heat-treated tempers. AA 6063-6 vol. % SiC composite subjected to 35% cold rolling and solution heat-treatment, where a more even dispersion of the SiC particles in the AA6063 matrix. A good uniform distribution of the silicon carbide particulates in the matrix of the AA6063 has produced the tensile properties and fracture toughness of the composites improved significantly with the adoption of the cold rolling and solution heat treatment process. The fracture toughness of the composites with increase in SiC volume percent is shown in Fig.7 [15]. The fracture toughness was decreased with increase in volume percent of SiC however improves with degree of cold rolling before solution heat treatment. The fracture micro-mechanism in particulate reinforced MMCs had been reported to be due to particulate cracking, interfacial cracking or particle deboning [16, 17].

The reduced porosity and considerable elimination of particle clusters in the composites might be responsible for the slight improvement in the fracture toughness of the composites. The Al-B_4C composites were produced by modified stir cast route with different weight percentage (4, 6, 8, 10 and12) of reinforcement and the microstructure, mechanical properties were evaluated [18]. The optical, SEM metallographic study and XRD analysis revealed the presence of B_4C particles in the composite with homogeneous dispersion. The micro and macro hardness of the composites were increased from 51.3 HV to 80.8 HV and 34.4 BHN to 58.6 BHN with respect to addition of weight percentage of B_4C particles.

The reinforcement of particle has enhanced the tensile strength of aluminum matrix and composites from 185 MPa to 215 MPa. Fatih Toptan et al. [19] synthesized the AA1070 and AA6063 matrix B_4C reinforced composites by casting method. The K_2TiF_6 was used to improve the wettability between B_4C and liquid aluminium metal. Heat treatment (T6) was performed for AA6063 matrix composites by solution treatment at 510°C for 24 hr, followed by quenching in water, then aging at 180°C for 4 hours. Reasonably homogeneous distribution was observed on low magnification SEM images of AA1070/B_4C and AA6063/B_4C composites as shown in Fig. 8. The EDS analysis taken from the reaction layer confirmed that the reaction layer consists of TiB_2 and TiC.

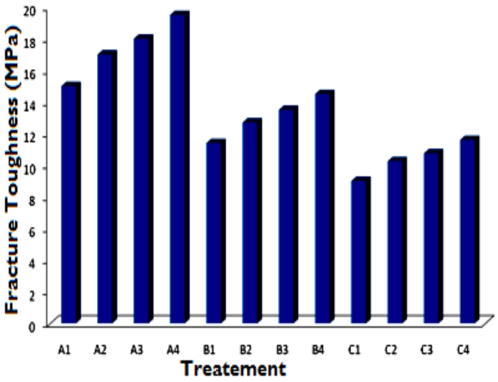

Fig. 7 Fracture toughness for the AA 6063-SiC composites [15]

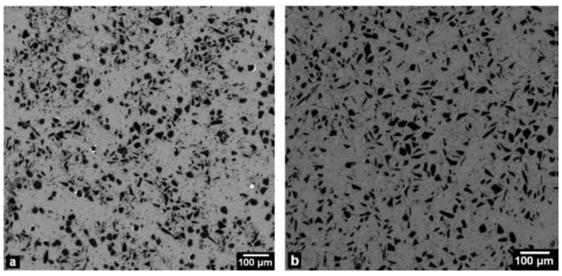

Fig.8 BSI SEM images of: (a) AA1070 matrix (b) AA 6063 matrix 10% (wt.) B_4C reinforced composites [19]

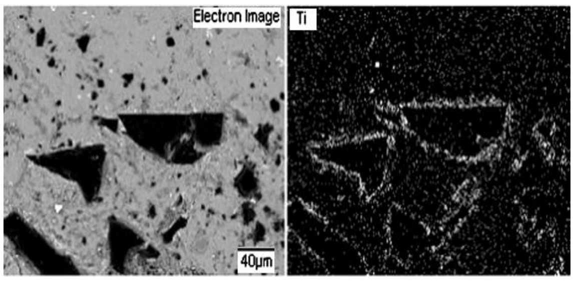

Fig.9 BSI SEM image and matching Ti elemental map of AA6063/B_4C composite [19]

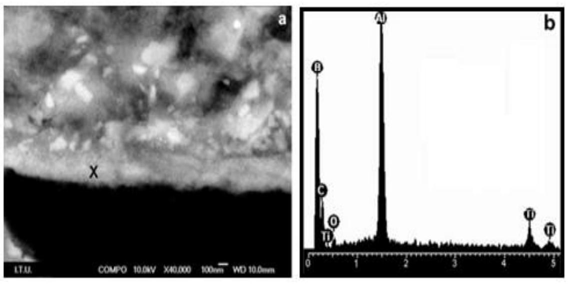

Fig.10 (a) SEM image of the interface at AA6063-B_4C composite (b) EDS spectrum taken from ‘‘x” marked point in (a) [19]

Figure 9 shows SEM image and matching Ti elemental map of AA6063/B_4C composite. The high magnification SEM image of the matrix/reinforcement interface and the EDS analysis of the interface taken from AA6063/B_4C (10 wt. %) composite is presented in Fig.10. Baki Karamıs et al. [20] investigated the effect of cooling rate during homogenization treatment of AA6063 aluminum alloy. The AA6063 material is cooled with a lower cooling rate to room temperature, Mg_2Si phases are precipitated as coarse grains. The size of Mg_2Si phases is decreased and percentages of Mg, Si and Fe in the matrix are raised parallel to the increased cooling rate. Cooling rate during the homogenization treatment determines the precipitation properties of metallic phases particularly Mg_2Si phases in the material. Figure 11 show the effect of cooling rate on critical deformation rate and it shows critical deformation rate is increased with the cooling rate, since the energy given to the material during the heat treatment is increased; the critical deformation rate is also decreased with the treatment temperature. From Fig. 12 it is understood that the grain size of the treated material is decreased by the cooling rate. The size of Mg_2Si particles decreased and the critical deformation rate is increased with the cooling rate. Maximum grain size of the AA6063 material decreased with the annealing temperature. The critical deformation rate decreased and maximum grain size increased with the annealing temperature.

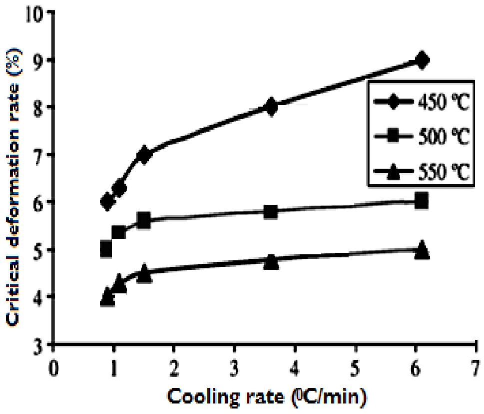

Fig.11 Effect of cooling rate on critical deformation rate [20]

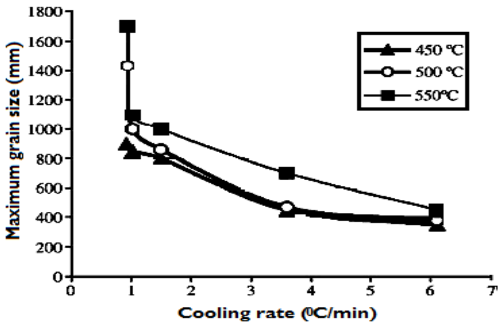

Fig.12 Effect of cooling rate on maximum grain size at different homogenization temperature [20]

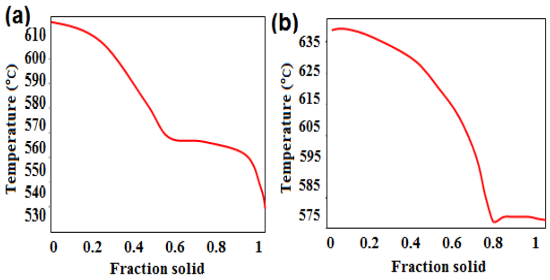

Fig.13 Temperature vs. fraction solid for (a) A356; and (b) Al-4%Si, at a cooling rate, after solidification, of 0.06 $°Cs^{-1}$ [21]

Brabazon et al. [21] established the effects of controlled stirring during solidification of aluminium alloys on the microstructure and mechanical properties, and they compared with conventionally gravity chill cast material. A novel device comprising a grooved reaction bonded silicon nitride rod rotating in a tube like crucible was used to process aluminium alloys in the mushy state.

Figure 13 shows the graph drawn between temperature and fraction solid graphs, as determined for the Chill cast A356 and Al-4%Si. A356 was observed to have higher fatigue strength during these initial tests. Stress amplitude of 134 MPa was determined and used for the A356 rotating fatigue tests and 104 MPa for Al-4%Si. Fatigue properties of the stir cast alloy vary inversely with porosity.

Hashim et al. used relatively low cost stir casting technique for the production of silicon carbide/aluminium alloy MMCs [22]. In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix alloy must be uniform, and the wettability or bonding between these substances should be optimized. The porosity levels need to be minimized and the chemical reactions between reinforcement materials and the matrix alloy must be avoided.

Table 1 shows a comparative evaluation of the different processes commonly used for discontinuously reinforced metal matrix composites production. The stir casting method is potentially very cost effective, but common adoption is dependent on a satisfactory resolution.

Table 1. Comparison of the different techniques used for DRMMC fabrication [23]

Methods/ Properties	Stir casting	Squeeze casting	Spray casting	Powder Metallurgy
Range of shape	Wide range of shapes;	Limited by preform shape;	Limited shape;	Wide range;
Size	Larger size; Up to 500 kg	Up to 2 cm height	Large size	Restricted size
Metal yield	Very high, >90%	Low	Medium	High
Volume fraction	Up to 0.3	Up to 0.45	0.3±0.7	-
Damage to Reinforcement	No damage	Severe damage	-	Fracture
Cost	Least expensive	Moderate	Expensive	Expensive

3. Reinforcements of AMCs

The reinforcement materials used are typically ceramics because they provide a very attractive combination of stiffness, strength, and relatively low density. The various reinforcements and properties are summarized in Table 2. The reinforcement is to provide increased stiffness and strength to the unreinforced matrix, ceramic particles with their large elastic modulus and high strength are ideal as the reinforcing particles. Many of the ceramic particles of concern are thermodynamically unstable when they are in contact with pure metals, and will react to form reaction compounds at the interface between the particles and the surrounding matrix. TiC particles can be synthesized in situ by several ways such as salt reaction with the molten Al, addition of Al-Ti-C powder compact or by the reaction of CH_4 gas with the melt.

Table 2. Properties of different reinforcements [24-27]

Reinforcement	**Density g/cm^3**	**Melting Point ^{o}C**	**Hardness Vickers GPa**	**Elastic modulus GPa**	**Thermal Conductivity w/m/K**
TiC	4.93	3067	24-32	400	17-32
TiB_2	4.52	3225	25-35	560	60-120
SiC	3.22	2973	28-33	410	126
Al_2O_3	3.99	2043	18-21	400	30
AlN	3.26	2200	11.8	331	285
ZrB_2	6.09	3000	22-26	350	23

Cho et al. has produced Al-TiC in-situ composites with the addition of Ti and C to the melt in the form of powders or compact in to pellets/performs, which react with the molten Al and form TiC inside the melt [28]. The nucleation of the carbide occurs through titanium diffusing to the carbon containing bubble and precipitating TiC on the surface as carbide via a solid-liquid chemical reaction. The TiC particles were in the size range of 0.1-2.0 µm.

Rai et al. synthesized Al-10TiC in situ composite by the reaction of molten Al with K_2TiF_6 and graphite powder at 1200^{o}C [29]. The SEM micrograph and the XRD analysis of composite show the presence of TiC, and the TiC particles were segregated toward the grain boundary. Rolling and forging were carried out to de-agglomerate and re-distribute the TiC particles, and it was found that the size of the TiC agglomeration was reduced. Hot forging of Al-10TiC showed an increase of 40 and 20% in ultimate tensile strength and yield strength, respectively, compared with Al-3TiC composite. The effect of hot extrusion on wear properties of Al-15 wt. % Mg_2Si in-situ metal matrix composites and showed an improvement in wear resistance for higher extrusion ratio samples and observed abrasion to be the dominant wear mechanism in all extruded composites [30]. Effect of Ti on extruded in-situ Al-15% Mg_2Si composite showed 40% improvement in UTS and elongation also showed changeover from brittle fracture mode in the as-cast composite to ductile fracture extruded specimens.

Birol [31] synthesized Al-TiC in-situ composite by K_2TiF_6 and graphite powder addition to Al melt at 1000^{o}C. It was observed that with the increase in reaction time of 1, 5, 10 and 20 min, the Al_3Ti phase fraction reduced along with an increase in TiC phase. The reaction sequence between K_2TiF_6 and graphite powder leading to TiC formation is as follows:

$$3K_2TiF_6+4Al \rightarrow 3Ti+3KAlF_4+K_3AlF_6$$
$$Ti+3Al \rightarrow Al_3Ti$$
$$Al_3Ti+C \rightarrow TiC+3Al$$

LI Jian-guo et al. [32] made an attempt to refine the performance of AlTiC, Al5.5Ti0.25C and Al6.5Ti0.5C master alloys containing high Ti and C content. They prepared and used grain refining experiments of 99.8% commercial pure aluminum. The performance was compared with two types of

Al5TilB refiners whose performance was now a day considered to be the best. This method is also found to be applicable in the production of aluminum foil with micron thickness. The size, distribution and surface condition of second phase particles in master alloys had complicated effects on their performance during refining process.

Peijie et al. [33] have synthesized Al-15 wt. % TiC in situ composites by the self-propagating high temperature synthesis reaction between the Al melt and Ti-C powder. Thermodynamic calculations were made for Al-15 wt. % TiC at initial temperatures of aluminum melt 900^{o}C and 1000^{o}C and at Ti/C molar ratios with and without Al powder. SHS reaction was observed with formation of flashes and sparkling once the powder mixtures were added in to aluminum melt. Excess C powder increases the adiabatic temperature and leads to formation of Al_4C_3 phase, and it is considered to be unfavorable in Al-TiC composites.

Herman et al. [34] have improved the tensile strength of AA6063 by adding manganese element. AA6063 containing 2.5 wt. % Mn which has been subjected to solution treatment and artificial aging and followed by 14 days natural aging has ultimate tensile strength of 189.55 MPa whereas as-cast AA6063 has the ultimate tensile strength of 61.33 MPa.

Sallahauddin et al. [35] developed and studied the wear properties of Al7025-B_4C reinforced aluminum metal matrix composites. Al7025 alloy was taken as the base matrix and B_4C particulates were used as reinforcements. For each composite, reinforcement particles were pre-heated to a temperature of 500^{o}C to improve wettability and distribution. A pin-on-disc wear testing machine was used to evaluate the wear rate, in which a hardened EN32 steel disc was used as the counter face. The results indicated that the wear rate of the composites was lesser than that of the AA7025 matrix. However, the material loss in terms of wear rate increased with the increase in load and sliding speed both in case of composites and the alloy.

Uvaraja et al. added the amount of SiC and B_4C particles to aluminium alloy enhances hardness as compared to unreinforced alloy [36]. Hybrid composites having AA6061-10 wt. % SiC and 3 wt. % B_4C shows optimum combination to obtain high hardness and good toughness. In addition to this it was observed that, hardness of the composites found increased with increased filler content and the increases in hardness of AA6061-SiC-B_4C and AA7075-SiC-B_4C hybrid composites are found to be 75-88 BHN and 80-94 BHN respectively as compared to unreinforced alloy.

4. Mechanical and Tribology Properties of AMCs

The factors that determine properties of composites are volume fraction, microstructure, homogeneity and isotropy of the system and these are strongly influenced by proportions and properties of the matrix and the reinforcement. The properties such as the young’s modulus, shear modulus, Poisson’s ratio, coefficient of friction and coefficient of thermal expansion are predicted in terms of the properties and concentration.

Saravanakumar et al. [37] investigated hybrid aluminum matrix composites manufactured for different combinations of alumina and graphite by using stir casting method. The scanning electron micrographs revealed the effect of reinforcement on the matrix grain size, distribution of reinforcement and clustering of reinforcement in the matrix. The increase in percentage of reinforcement up to 6% alumina improved the hardness, compressive strength, impact strength and flexural strength of the hybrid composite. This was recognized by uniform distribution of reinforcement and further increase of the same weakens the mechanical properties due to clustering. Highest hardness, compressive strength, impact strength and flexural strength was observed for AA 6063-6 wt. % Al_2O_3-1 wt. % Gr hybrid composite.

The feasibility and dry turning characteristics of in-situ Al-4.5%Cu/TiC metal matrix composites using uncoated ceramic inserts [38]. Al-4.5% Cu metal matrix alloy reinforced with 5, 7 and 10 wt. % of TiC using in-situ method. The increase in wt. % of TiC reinforcement increases the tensile strength and hardness of Al-4.5%Cu/TiC MMCs with reduced ductility. The good quality of surface finish was observed at 120 m/min cutting speed. The high value of cutting force and surface roughness was observed during dry condition machining at higher feed rate is 0.36 mm/rev and depth of cut is 1.0 mm. The formation of BUE was more prominent at lower cutting speed is 40 m/min and continued to decrease with increasing cutting speed. With less than 10% of TiC reinforcements, mostly helical and C-types chips were produced at relatively higher cutting speed. Discontinuous and short length chips were produced with 10% of TiC reinforcements during the machining.

Patel et al. [39] has investigated the influence of machining parameters on surface finish turning 6063 Al/TiC metal matrix composite. Polycrystalline diamond (PCD) insert of fine grade was selected for machining of Al-TiC metal matrix composites, because it had been found that PCD tool is best choice for machining of MMCs due to its high wear resistance. The surface finish of work piece having 5 % TiC is better than work piece having 10 % TiC. The result shows the increase of feed rate increase the surface roughness.

Yigezu et al. have reported the abrasive wear characteristics of in-situ synthesized Al-12%Si/TiC composites [40]. Al-12%Si/TiC composites were fabricated by melting the Al-12%Si matrix in the muffle furnace with graphite crucible, at 800^{o}C commercial pure titanium was included. Subsequently at 1000^{o}C activation charcoal was added and the temperature increased to 1200^{o}C and hold for 30 min. The amount of titanium and activation charcoal added was in account of achieving the desired wt. % of TiC. The percentage error between the experimental and calculated values of the weight loss and coefficients of friction for both full factorial and conformation tests is less than 10% and 5%, respectively. The abrasive wear for the in situ Al-12%Si/TiC composites with target weight loss and coefficient of friction set at 0.04007 g and 0.40001 respectively was obtained within accuracy of 6.06%.

Rice husk ash (RHA) is a potential particulate reinforcement to produce aluminum matrix composites economically. Compo casting method was applied to produce aluminum alloy AA6061 reinforced with various amounts (0, 2%, 4%, 6% and 8%, mass fraction) of RHA particles [41]. The RHA particles were thermodynamically stable at the compo casting temperature. There was no interfacial reaction between the RHA particle and the aluminum matrix. The interface between the aluminum matrix and the RHA particle was clear and the RHA particles were bonded well with the aluminum matrix. The reinforcement of RHA particles enhanced the mechanical properties of the AMCs. AA6061/8% RHA AMC exhibited 167.27% higher micro hardness and 57.42% higher UTS compared to the unreinforced AA6061.

Rajesh Kumar et al. [42] explained the operating parameters of the AA6061 composite contains SiC, Al_2O_3 & Gr reinforcements by stir casting process at less cost. The flow rate of reinforcements measured was 0.5 gram per second, dispersion time was taken as 5 minutes. After stirring 5 minutes at semisolid stage slurry was reheated and hold at a temperature 900°C to make sure slurry was fully liquid. Mold was preheated at temperature 500°C before pouring the molten slurry in the mold.

Radhika et al. [43] investigated the wear and frictional properties of 9% alumina and 3% graphite reinforced Al-Si10Mg hybrid metal matrix composites. They performed dry sliding wear test using a pin-on-disc wear tester. Experiments were conducted based on the plan of experiments generated through Taguchi’s technique. A L_{27} Orthogonal array was selected for analysis of the data. Also they investigated the influence of applied load, sliding speed and sliding distance on wear rate, as well as the coefficient of friction during wearing process using ANOVA and regression equations. The sliding distance had the highest influence followed by load and sliding speed.

Christy et al. [44] has manufactured Al-TiB_2 metal matrix composite using the in-situ salt metal reaction. TiB_2 as the particulate addition the properties of Al 6061 alloy was greatly improved. A comparison of the mechanical properties and the microstructure of Al 6061 alloy with Al-TiB_2 metal matrix composite containing 12% by weight TiB_2 exhibited higher values of hardness, tensile strength and young’s modulus than the base alloy. The ductility of the composite was found to be slightly lower than that of the Al 6061 alloy.

Ram Naresh Rai et al. [45] evaluated the machining behavior of Al-TiC composites and compared them with those of extensively used Al-Si alloys and Al-$TiAl_3$ composite. High volume fraction of TiC reinforced particles causes discontinuous and favorable chip formation without any buildup edge formation during machining of Al-TiC composites. Cutting force was less in the case of Al-TiC composites as compared to those for Al-$TiAl_3$, Al-Si and pure Al. During chip formation, deformation occurs along the TiC particles, which facilitates the formation of micro cracks. These micro cracks propagate at the particle/matrix interface leading to fracture through the chip thickness. Al-TiC composite produced by the in situ technique has been found to have good machinability.

Michael Rajan et al. [46] AA7075/TiB_2 AMCs were successfully synthesized by the in situ reaction of inorganic salts such as K_2TiF_6 and KBF_4 to molten aluminum. The in situ reaction resulted in the formation of TiB_2 particles. No other intermetallic compounds in significant quantity were detected. Most of the TiB_2 particles were located in inter granular regions. The microstructures of the developed AMCs revealed a uniform distribution of TiB_2 particles having clear interface and good bonding.

The in-situ formed TiB_2 particles displayed various shapes such as cubic, spherical and hexagonal. The mechanical properties of the AMCs improved when the content of TiB_2 particles was increased.

Gavgali et al. [47] developed AA6063 aluminium alloy in artificially aged conditions. The artificial aging produces the harder structure that is attributable to acceleration of precipitation of Mg_2Si and other phases such as $CuAl_2$ and AlFeSi. The microstructure was altered with the aging treatment, and it was observed that the precipitates in the structure dispersed finely with the increasing of the aging time. The aging treatment caused a decrease in the coefficient of the friction after attaining the steady state, exceeding the transient periods depending on aging and solution time. The lowest coefficient of the friction was obtained in samples aged at 180^0C for 5 hrs after solution treatment at 510^0C for 6 hrs. The wear coefficients and wear loss in as cast samples are greater than that in the aged samples. The increasing of the aging time at the reduction of the wear coefficients was more effective than that of the solution time.

Herman Pratikno has reported that the erosion-corrosion is an accelerated corrosion attack in metals due to a relative motion of corrosive fluid [48]. The AA6063 were prepared by casting. The alloys were solutionised at 535^oC for 6 hours and followed by water-quenching. The alloys were then artificial aged at 200^oC for 5 hours and followed by natural aging for 14 days. Erosion-corrosion tests were carried out in 3.5% NaCl solution. The solution was stirred using a magnetic stirrer at rotation speeds of 100, 200, 300, 400, 500 and 600 rpm. It was found that the solution and aging treatments have increased erosion-corrosion resistance of AA6063. A better erosion-corrosion resistance was obtained by a combining both artificial and natural aging process.

Lekatou et al. [49] produced aluminium matrix composites by the addition of submicron sized TiC and WC particles of low (up to 1.0 vol. %) content into a melt of Al1050. Casting was assisted by the use of K_2TiF_6 as a wetting agent and mechanical stirring to limit particle clustering. An extensive presence of intermetallic phases was observed in the cast products, as a result of both the inoculation by K_2TiF_6 and the intensive mainly due to the fine carbide particle size reactivity of the carbides with the molten matrix. Particle distribution was reasonably uniform comprising both clusters and isolated particles. The intermetallic particle dispersion has changed the intended nature of the composites.

Alaneme et al. [50] studied the influence of alumina volume percent and solution heat treatment on the corrosion behavior of AA6063 composites and its monolithic alloy in salt water, basic and acidic environments is investigated. AA6063-Al_2O_3 particulate composites containing 6, 9, 15 and 18 volume percent Al_2O_3 were produced by adopting two step stir casting. Mass loss and corrosion rate measurements were utilized as criteria for evaluating the corrosion behavior of the composites. It is observed that AA6063-Al_2O_3 composites exhibited excellent corrosion resistance in NaCl medium than in the NaOH and H_2SO_4 media. The unreinforced alloy exhibited slightly superior corrosion resistance than the composites in NaCl and NaOH media but the composites had better corrosion resistance in H_2SO_4 medium. Furthermore, solution heat treatment resulted in improved corrosion resistance for both the composites and the unreinforced alloy while the effect of volume percent Al_2O_3 on corrosion resistance did not follow a consistent trend.

5. Conclusion

A lot of work has been done on aluminium based metal matrix composites with various reinforcements, different sizes and manufactured techniques either by stir casting technique and then subjected to study the mechanical and machining properties. Alloy composition and its condition influence the wear rate. With increase in weight percentage of reinforcement in the matrix the wear resistance of composite increase. The hardness also increased with increase in weight percentage of reinforcement.

The investigations of several researchers have been thoroughly studied and their conclusive findings have been recorded concerning the processing and properties of composites through various routes.

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